"ELECTRICAL PROTECTION GROUNDING FUNDAMENTALS"

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1. GENERAL

1.1 This section provides REA Borrowers, Engineers, and other interested parties with information for use in the design, construction, and operation of REA Borrowers' Telephone Systems. It discusses basic factors affecting earth resistivity and grounding. It also describes techniques for obtaining and measuring a good ground, and values of earth resistivity for use in other calculations.

1.2 The term "ground" for our purposes is defined as a conducting connection by which a circuit or equipment is connected to the earth. The connection is used for establishing and maintaining the potential of the earth, or approximately that potential, on the circuit or equipment connected to it. The "ground" consists of a grounding conductor, a bonding connector, a grounding electrode, and the soil in contact with the electrode.

1.3 In protection applications, grounds have two basic uses:

1.31 For natural phenomena, such as lightning, grounds are used to drain the foreign potential from the system before personnel can be injured or vulnerable system components can be damaged.

1.32 For foreign potentials caused by electric power system faults with ground return, grounds aid in causing rapid operation of the power system protection relays by providing additional fault current paths, thus causing removal of the foreign potential as rapidly as possible. In addition, the ground should drain the foreign potential before the telephone system can be seriously damaged, or personnel injured.

1.4 Ideally, a ground should be of zero ohms resistance. In reality, this value cannot be obtained due to the series resistances shown in Figure 1. In subsequent Paragraph's, methods of obtaining a ground of the smallest practical resistance will be discussed.

2. PHENOMENA AFFECTING GROUND RESISTANCE

2.1 One cannot simply drive a rod into the soil and expect to obtain a good, low resistance ground. Many factors, both natural and man-made, may affect results.

2.2 Earth resistivity. The electrical resistivity of the earth (resistance of the earth to the flow of current) is of major importance. The unit of earth resistivity, the meter-ohm, is defined as the resistance, in ohms, between opposite faces of a cube of earth 1 cubic meter in volume. An alterna unit of measure, the ohm-centimeter is defined as the resistance in ohms, between opposite faces of a one centimeter cube of earth. To convert meter-oh to ohm-centimeters, multiply the former by 100.

2.21 Earth resistivity varies over a considerable range within the United States; from a few meter-ohms along some coasts to many thousands of meter-ohms in rocky, mountainous country. Figure 2, provides very general data on average earth resistivity throughout the United States.

2.22 In addition to regional variations, earth resistivity may vary widely within very small distances due to local soil conditions. Table I lists typical ranges of earth resistivity for various types of soil. This table should be useful in selecting locations at which a ground is to be constructed.

TABLE I: RESISTIVITY OF VARIOUS SOILS

SOIL	RESISTIVITY RANGE (M-Ω)		
Loam	5	-	50
Clay	4	-	100
Sand/Gravel	50	-	1,000
Limestone	5	-	10,000
Shale	5	-	10,000
Sandstone	20	-	2,000
Granite		1,000	
Slates	600	-	5,000

2.3 Soil Moisture: Nearly any soil, with a zero moisture content, is a nearly perfect insulator. Fortunately, this condition is very rarely encountered, except in desert areas or during periods of severe drought. Figure 3, illustrates the typical affect of moisture on soil resistivity. I should be noted that, above 17%, additional moisture has little affect. Bel this figure resistivity rises rapidly until, at 2%, it reaches 100 times its value at 17%. Thus, a good ground connection should always be in contact wi soil having a ground water content in excess of 17%. Local well drillers shc be able to provide information concerning depth of the water table in their area.

2.4 Soil Mineral Content. Water, with no mineral salt content, is nearly as good an insulator as soil with no moisture content. Figure 4 illustrates the effect of mineral salt content on soil resistivity. Soils which lack adequate soluable mineral salts may be encountered from time to time. In this situation, chemically treating the soil surrounding the electrode, as covered in Paragraph 3.3 may provide an acceptable ground.

2.5 Temperature: As the temperature of soil decreases, resistivity increases. When soil temperature drops below the freezing point of water, resistivity increases rapidly, as shown in Figure 5.

3. GROUNDING TECHNIQUES

3.1 When planning a ground it is necessary to consider several factors in addition to the desire for a low resistance. These factors include:

3.11 Temperature Variations: The electrode should extend far enough below the local frost line to assure adequate contact with unfrozen soil in even the coldest periods.

3.12 Moisture Variations: The electrode should be at least partially in contact with moist soil during even the dryest periods.

3.13 Mechanical Strength/Protection: The electrode, and its connecting conductor must have mechanical strength adequate for the conditions to which they are subjected. The grounding conductor should be guarded as necessary to protect it from mechanical damage.

3.14 Installation Practicability: It must be possible to install the ground as designed, in the location desired. (i.e., a 60' driven ground rod would not be practicable on a granite mountain.)

3.15 Durability: How long must the ground last, and is periodic servicing acceptable?

3.16 Lead Length: Length of the lead between the building or equipment being protected and the ground should be as short as possible. Unnecessary length adds impedance to the ground which may lead to harmful voltage stresses when the circuit is subjected to high current surges. (i.e. #6AWG solid copper wire has a resistance of 0.4 ohms per kilofoot. Thus, the voltage drop across 100 feet of this wire when subjected to a 100KA surge would be 4,000 volts. Thus, while #6AWG copper wire is normally completely satisfactory for grounding, the lead length should be minimized).

3.17 System Interconnection: A good ground should not, in normal applications, be considered as an isolated component, but as part of a larger grounding system. For example, the shield of a buried cable is normally grounded at the central office and at points along the route. Thus, in order for the cable grounding system to operate correctly, shield continuity must be maintained.

3.12 Corrosion Considerations: In order to minimize corrosion problems f[or] the buried portion of metallic ground connections, the materials shou[ld] coordinate with those used by local power or pipeline operations. (e.g., if the local power system uses copper ground rods, the use of galvanized steel rods by the telephone company would be highly inadvisable. Ground currents [occ]ur between these two dissimilar metals would lead to rapid corrosion of the galvanized steel rods. Additional information on corrosion from this source is contained in REA Bulletin 161-23.)

3.2 Some of the more common ground electrodes are the driven ground rod, counterpoise, and Ufer ground. 1/

3.21 Driven ground rods.

3.211 Perhaps the most frequently used ground electrode is the simple driven ground rod. With careful tailoring of the number of rods, the spacing of multiple rods and in some cases, the rod length, to the local climate and geography, the driven ground rod becomes a most flexible and useful grounding tool. Figures 6-8, illustrate the general effect of these variables on the resistance of driven ground rod electrodes.

3.212 It should be noted that Figures 6-8 are all for uniform soil compositio[n]. In reality this situation is rarely encountered; the conditions in Figure 9 being more typical. In Figure 9, the soil appears in layers. Ground electrode resistance, in the situation shown in Figure 9, decreases slowly with depth until the water table is reached, then decreases more rapidly as increasin[g] lengths of rod are exposed to the moist soil.

3.213 The fact that layered soils are more common than uniform soils does not mean the data of Figures 6-8 are useless. These illustrations should be employed as <u>guidelines</u> of probable driven ground rod electrode behavior in most situations. Where soil is rocky, and frost or a low water table present no problems, many short rods may provide the optimum ground. Conversely, in soft sand, where the water table is deep, a single long ground rod may be the best choice. The engineer should examine all considerations and choose the option best suited for a given situation.

3.22 Counterpoise Ground

3.221 The counterpoise ground, used frequently on electric power systems, consists of a length of bare copper wire trenched into the soil and attached to the item to be grounded. Where local geography makes the driving of adequate rods difficult or impossible, the counterpoise ground may be employed. While location of the wires will vary depending on local terrain, a simple "X" shape with the four legs centered at the structure/device to be

1/ Named for H. G. Ufer who pioneered this technique.

rotected, is the recommended configuration. If more legs are added, an effect imilar to that when many rods are used at insufficient spacing occurs, and ne reduction in ground resistance may not be as great as anticipated. With ewer, but longer legs, the surge impedance of a long wire may become a problem. igure 10 illustrates the effect of length on the surge impedance of a counter-oise ground.

3.23 Ufer or Rebar 2/ Ground

3.231 Recent studies have shown that steel reinforcing rods encased in buried concrete may provide an effective ground. This technique is especially seful when local earth resistivity is high, but pre-construction planning is equired for use of the Ufer ground.

3.232 The 1975 NEC, Article 250-83a, places the following requirements on the Ufer ground:

"---Not less than 20 feet of (1) bare copper conductor not smaller than No. 4, or (2) steel reinforcing bar or rod encased by at least 2 inches of concrete and located within and near the bottom of a concrete foundation footing that is in direct contact with the earth."

ocal building codes should also be checked for additional restrictions.

3.233 As the Ufer ground depends on a good contact between the concrete and soil, no plastic vapor barrier 3/ or similar device should be employed f this form of grounding is to be used.

3.234 The rebar in most concrete structures is held together before concrete pouring only by twisted steel wires. In large numbers, such connections ill serve as a satisfactory interconnection for the Ufer or rebar ground--if he twisted wires are applied properly and tightened snugly.

3.235 As the rebar structure is inaccessible once concrete has been poured, provisions must be made for connections to this structure prior to the our. These connections should be welded firmly to the rebar, not rapped. Also, longer rebars, with many branch connections, should or these external connections as shown in Figure 11.

2/ "Rebar" is the construction tra

3/ The vapor barrier is a sheet of concrete and soil to prevent so thus preventing good electrical

3.236 While the Ufer ground may not in itself provide a totally satis ground in some situations, its use should be considered for new offices, microwave stations, and similar structures, employing reinforc concrete construction.

3.3 Chemical Soil Treatment

3.31 Chemical treatment of the soil surrounding a ground electrode wil lower the resistance of the ground. In situations where high ear resistivity and other factors combine to make a low resistance ground di to achieve, chemical treatment may be the only practical solution. Chem enhanced grounds are recommended only as a "last resort" since the chemi treatment is not permanent and must be renewed periodically.

3.32 Figure 12 illustrates one recommended method of applying chemicals the improvement of a ground. In this method a one foot deep circu trench is dug around the electrode, filled with chemical and covered with Chemicals most commonly used include:

Sodium Chloride (Common Rock Salt)
Calcium Chloride
Sodium Nitrate
Potassium Nitrate
Ammonium Sulphate

While the first two are less expensive, their effect on plant life may renc them less desirable than the subsequent fertilizers which are electrically acceptable.

3.33 Chemical treatment may last from six months to in excess of five yea before becoming ineffective. Actual time will depend on many factor including annual rainfall, quantity of chemicals used, porosity of the soil etc. To insure that chemically enhanced grounds are still effective, they should be measured every six months. If resistance has increased beyond an acceptable level, the chemical treatment should be repeated.

3.4 Common Grounding

3.41 In order to avoid serious personnel hazards the telephone company shou always connect its protector ground terminal to the electric power sys ground, and a metallic water system when these facilities exist at the locati in question.

3.42 In order to avoid personnel hazard this common bonding of the telephone and power grounds to each other and to the metallic water system is required by the 1975 National Electrical Code. By this bonding, differences in potential can be eliminated between the systems. (e.g. a person using the telephone with his feet on a radiator is not likely to suffer a shock should a lightning surge breakdown the insulation of the telephone set whereas a shocl may result, if common grounding is neglected.)

3.43 While attachment to the electric system ground and metallic water system may substitute for telephone company emplaced grounds, these grounds should be measured to determine that they are indeed satisfactory before reliance is placed in them. The increased use of plastic water pipe frequently renders a water system ineffective as a ground electrode, however, interconnection of the telephone ground to a metallic fixture in the water system is recommended from a safety standpoint. The use of plastic water pipe or an open neutral on the power system may result in total absence of the ground connection, unless verification is made.

4. MEASURING TECHNIQUES

4.1 Ground Resistance: Figure 13 illustrates a typical device employed in measuring resistance of a ground. A test signal is injected into the earth via the ground under test and flows back to the set by a remote return probe (C_2). By measuring voltage drop from the ground to a remote ground, and applying Ohm's Law, the ground resistance under test is derived.

4.11 The measuring probes should be placed in a straight line perpendicular to the ground under test for optimum results.

4.12 Care must be taken to assure that the current return probe (C_2) and voltage measuring probe (P_2) are located far enough from the ground under test to avoid being influenced by it. Care must also be taken to locate P_2 far enough from C_2 so that the field around C_2 will not influence the reading at P_2. The plot of resistance versus distance from ground under test in Figure , illustrates the result of shifting P_2 along a line between the ground under test and a properly located C_2. The curve's flattened area yields the correct value for ground resistance. If P_2 and C_2 are located too close to the ground connection under test, the curve will not flatten out and accurate readings will be difficult to obtain. Locating P_2 at a point 62% of the distance from the test connection to C_2 will usually produce valid data. However, a <u>series</u> of measurements should be taken with P_2 shifted from 50% to 75% of this distance to verify that the curve does indeed flatten thus signifying that P_2 and C_2 are correctly placed. If the curve does not flatten out, increase the distance from C_2 to the ground under test and repeat the measurements.

4.13 When ground systems, other than a single driven rod, are employed the locations of P_2 and C_2 become far more critical. The maximum diagonal of the ground grid should be calculated (e.g., on a 30' x 40' rectangle of driven rods, the maximum distance from corner to corner is 50'). Applying this value to Figure 14, the approximate spacings of the test electrodes can be determined. (For our 30' x 40' rectangle, P_2 should be 320' and C_2 450' from the ground connection under test.) As with readings on a single driven rod, P_2 should be moved and a series of readings taken to determine that the curve does indeed level out. If not, the distance from P_2 and C_2 to the ground connection under test should be increased and the tests repeated.

4.2 Earth Resistivity: The same test set used to measure ground resist can usually be used to measure earth resistivity. As shown in Figu four small probes are employed, and the C_1 and P_1 terminals, connected to for ground resistance measurements, are separated. The setup shown in Fi 15, measures the average resistivity of the soil between the C_1 and C_2 pro to a depth of A. If deeper measurements are required, the distance betwee probes should be increased.

4.21 To calculate earth resistivity from the meter readings (on meters n designed to read this parameter directly) obtained from the setup i Figure 15, employ the following formula:

$\rho = 2\pi AR$

Where: ρ = earth resistivity in meter-ohms or ohm-centimeters, depending unit of length employed for A.

$2\pi = 6.28$

A = distance between probes in meters or centimeters (Note: 1' = 0.305 m 30.5 cm)

R = Test set readings in ohms

4.22 When planning for a ground installation, "prospecting" for areas of earth resistivity can pay dividends by reducing the size and/or numl of electrodes required to achieve a given resistance. Wide variations in earth resistivity may make it possible to achieve a good ground at one poir and, only 100' or so away, make a satisfactory one impossible to achieve.

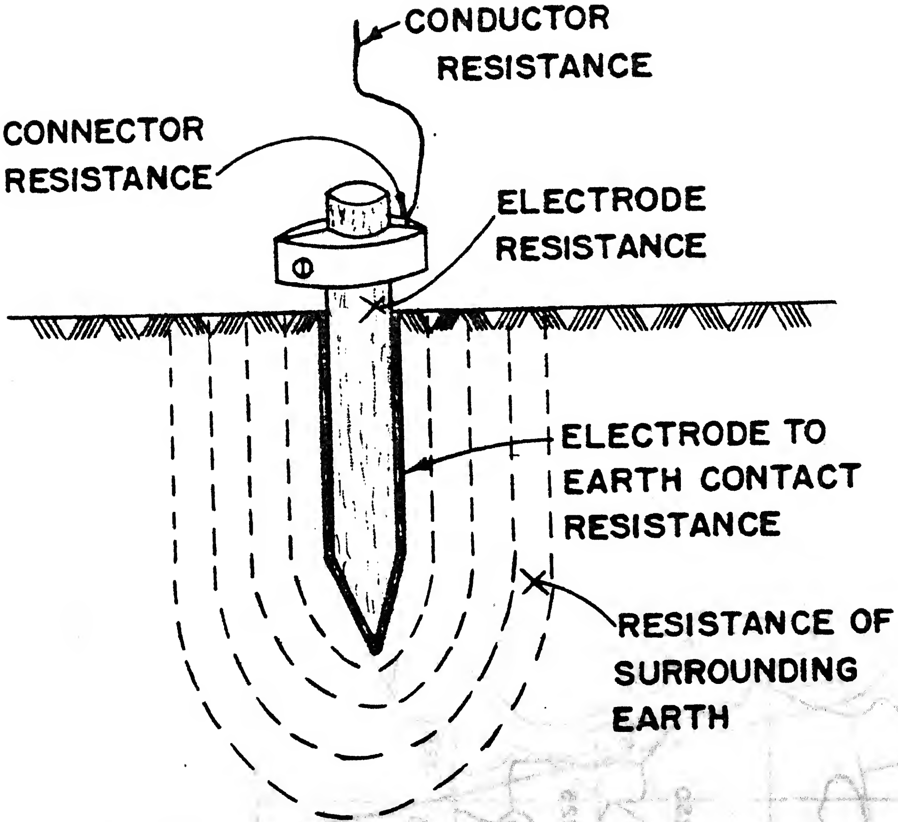


Fig. 1- COMPONENTS OF RESISTANCE IN A GROUND CONNECTION

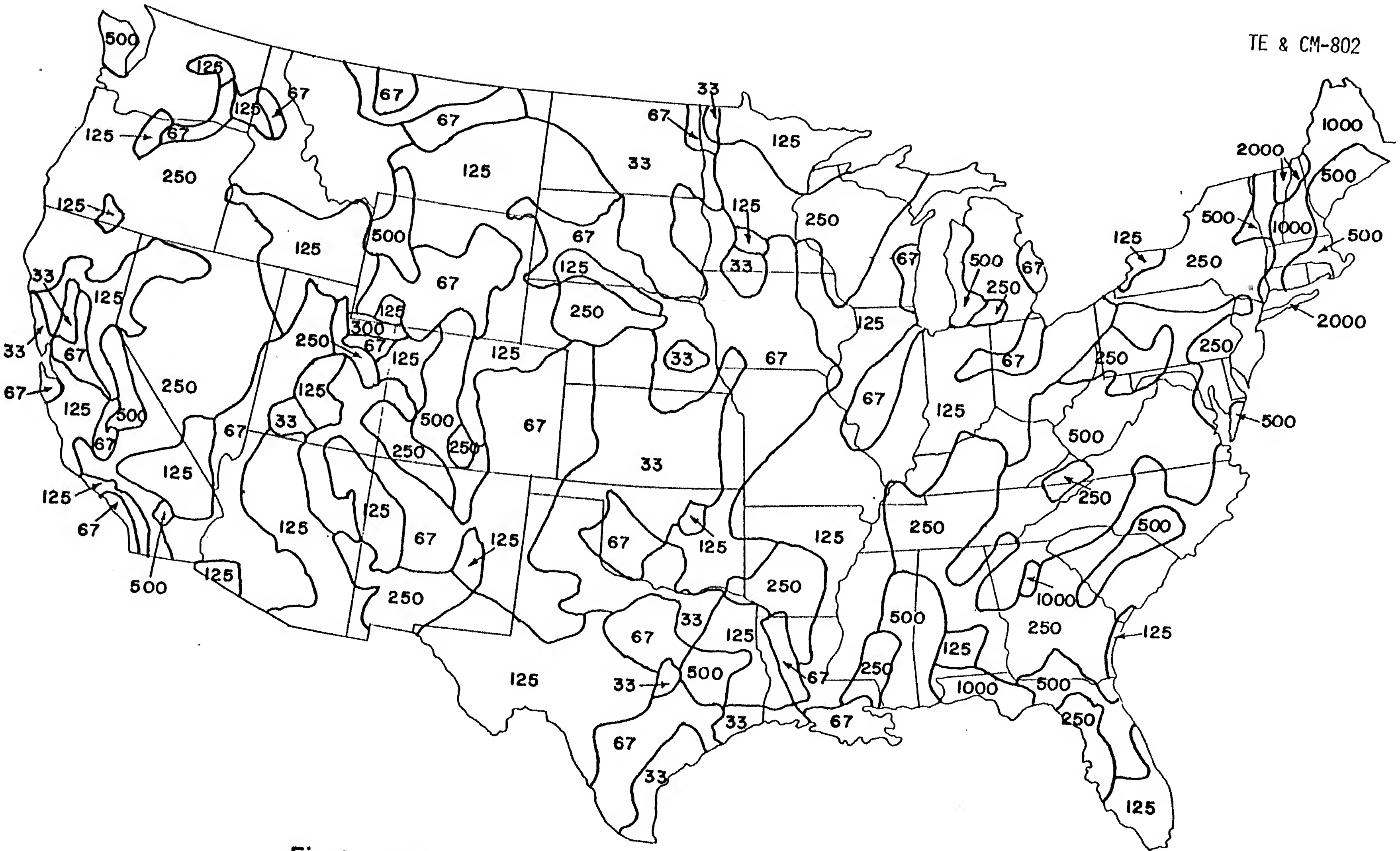


Fig. 2 ESTIMATED AVERAGE EARTH RESISTIVITY IN U.S.
(METER-OHMS)

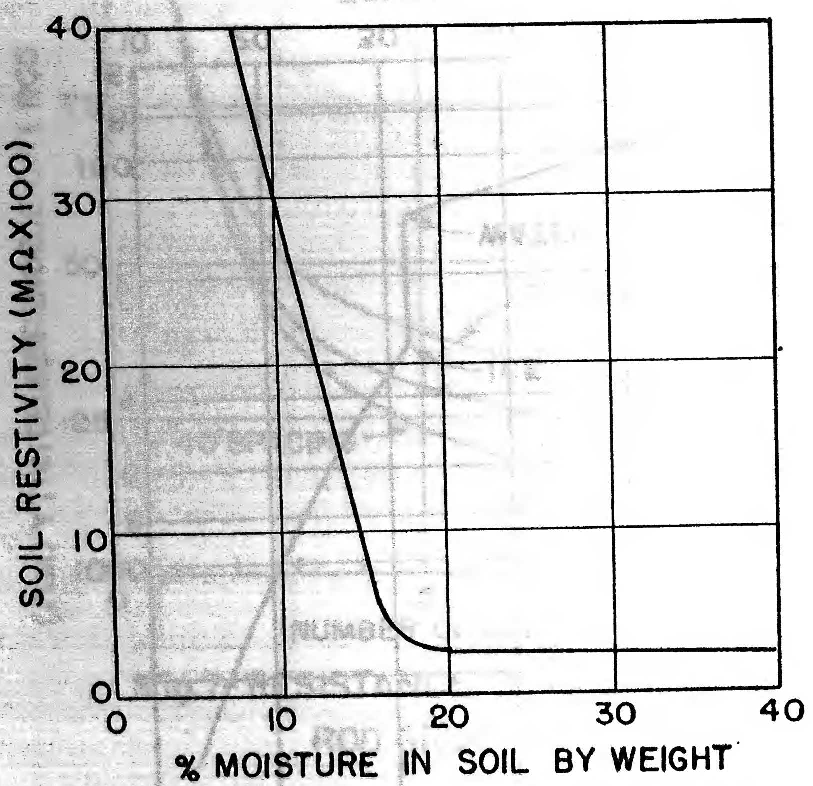


Fig. 3-TYPICAL VARIATION OF SOIL RESISTIVITY WITH MOISTURE

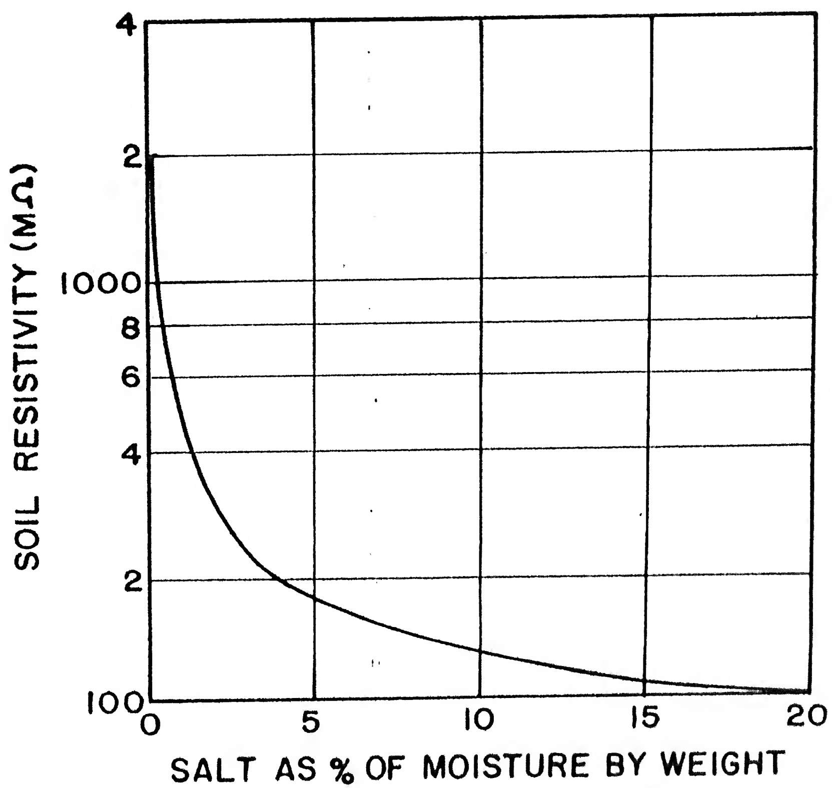


Fig. 4-TYPICAL EFFECT OF MINERAL SALT ON EARTH RESISTIVITY

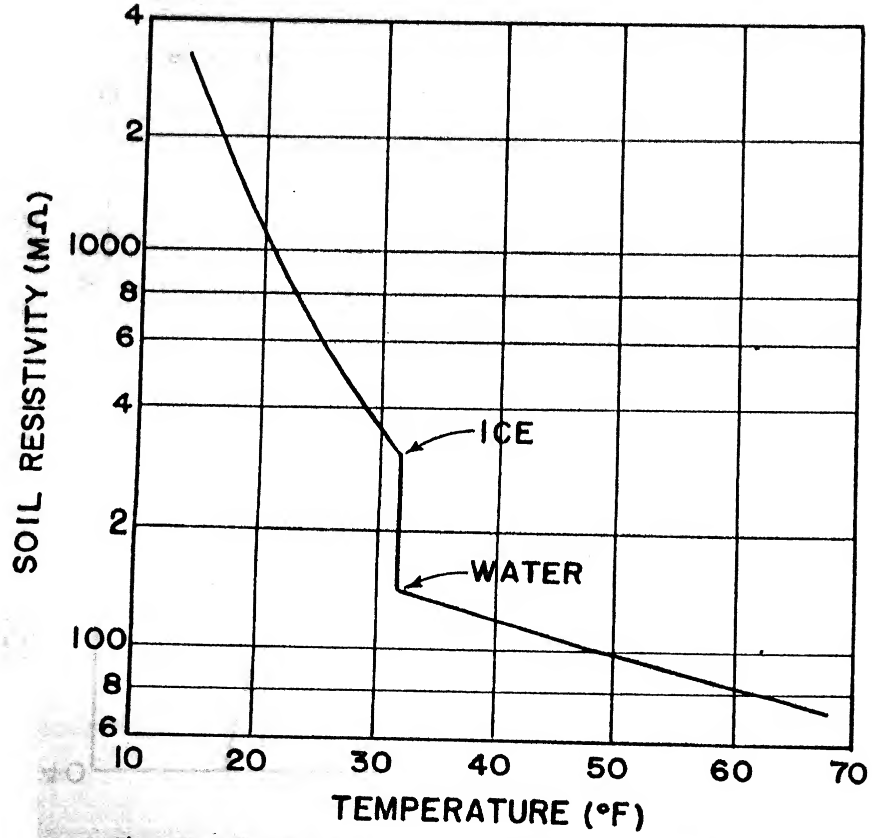


Fig. 5–TYPICAL VARIATION OF SOIL RESISTIVITY WITH TEMPERATURE

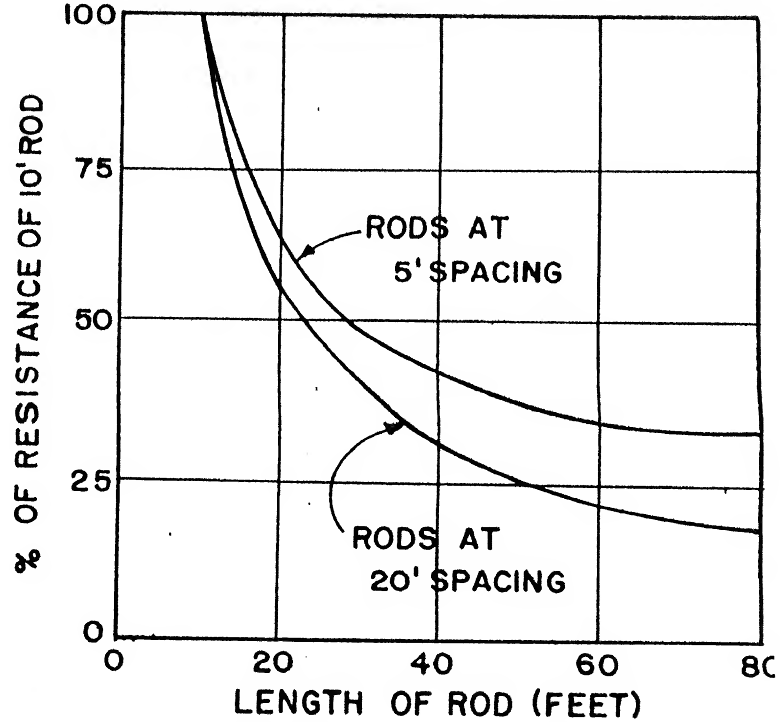


Fig. 6–EFFECT OF ROD LENGTH ON RESISTANCE FOR UNIFORM SOIL

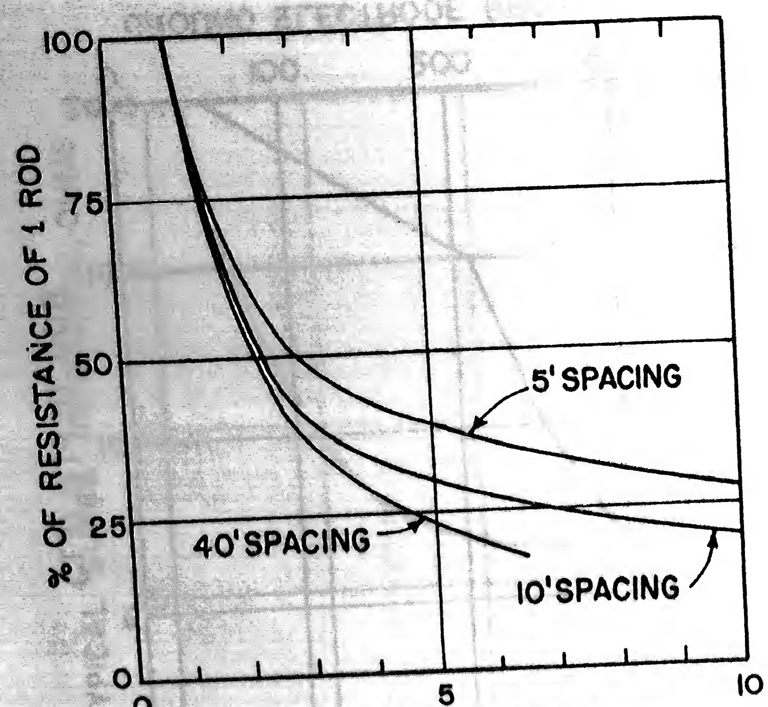


Fig.7- RESISTANCE OF MULTIPLE ROD GROUNDS

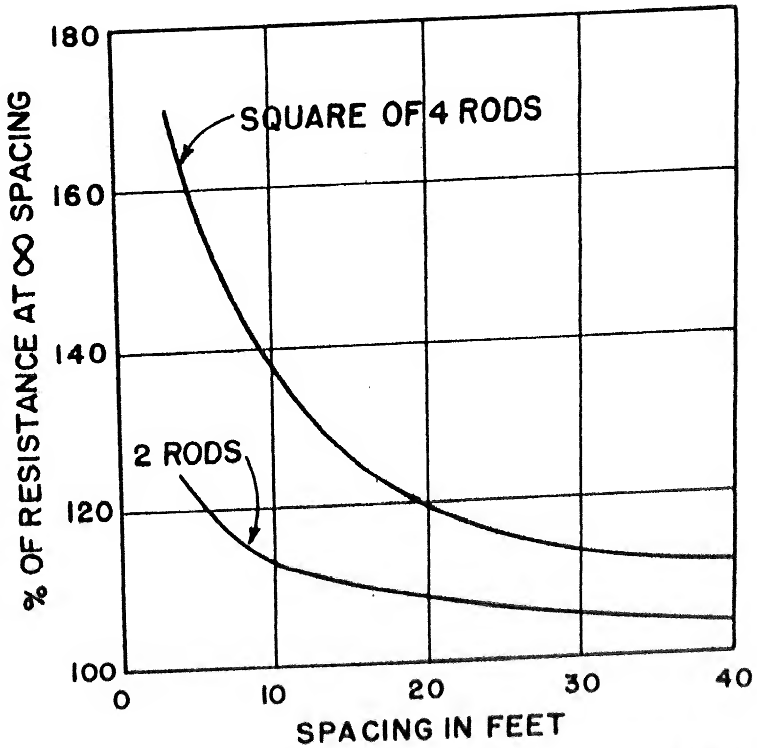


Fig. 8-RATIO OF RESISTANCE OF RODS AT CLOSE SPACING TO THE SAME RODS AT ∞ SPACING

NOTE: GREATER OVERLAP OF FIELDS CAUSES SMALLER
% RESISTANCE DROP AS MORE RODS ARE USED.
ACTUAL RESISTANCE IS LOWER WITH 4 RODS THAN 2.

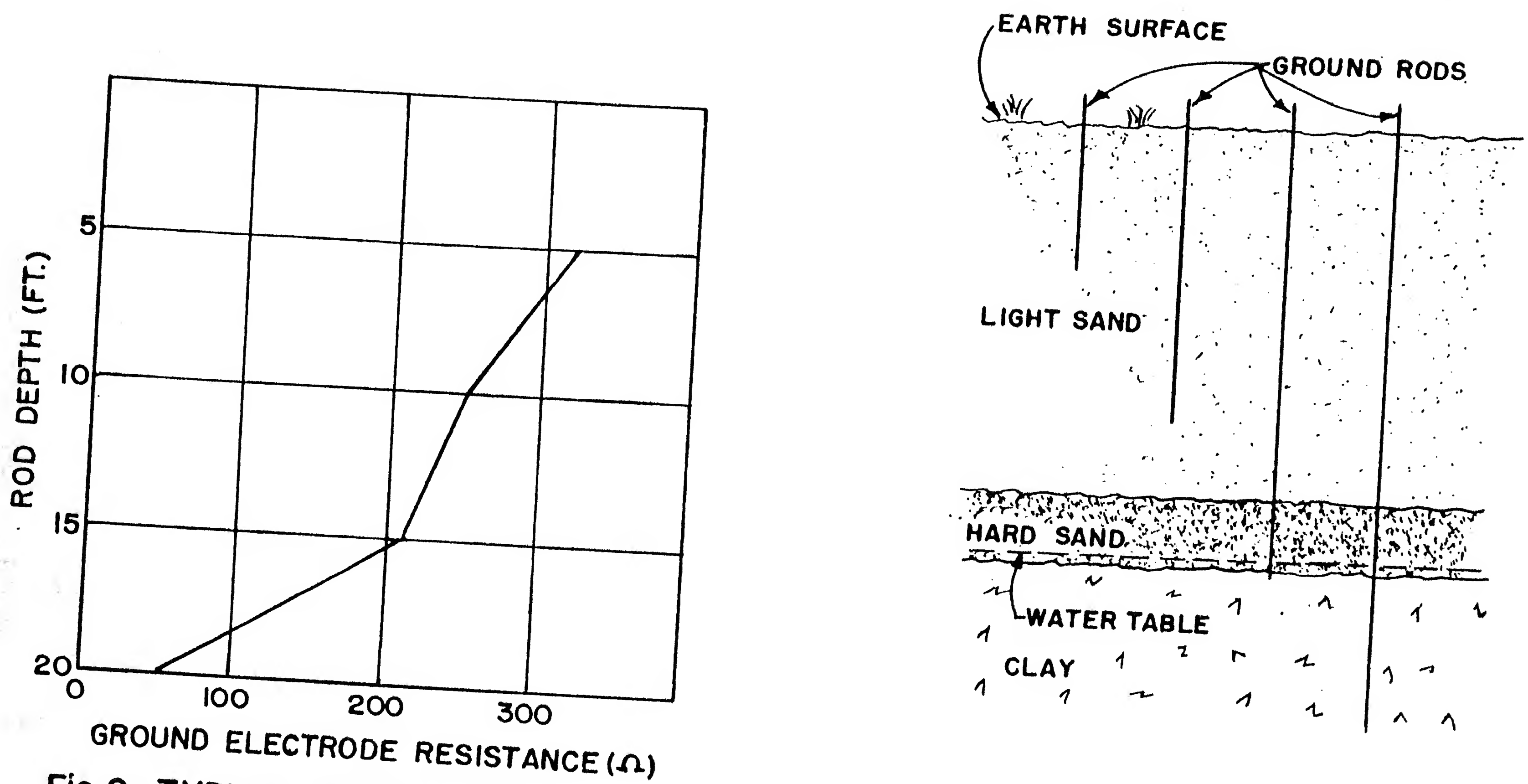


Fig.9–TYPICAL ROD LENGTH VERSUS RESISTANCE

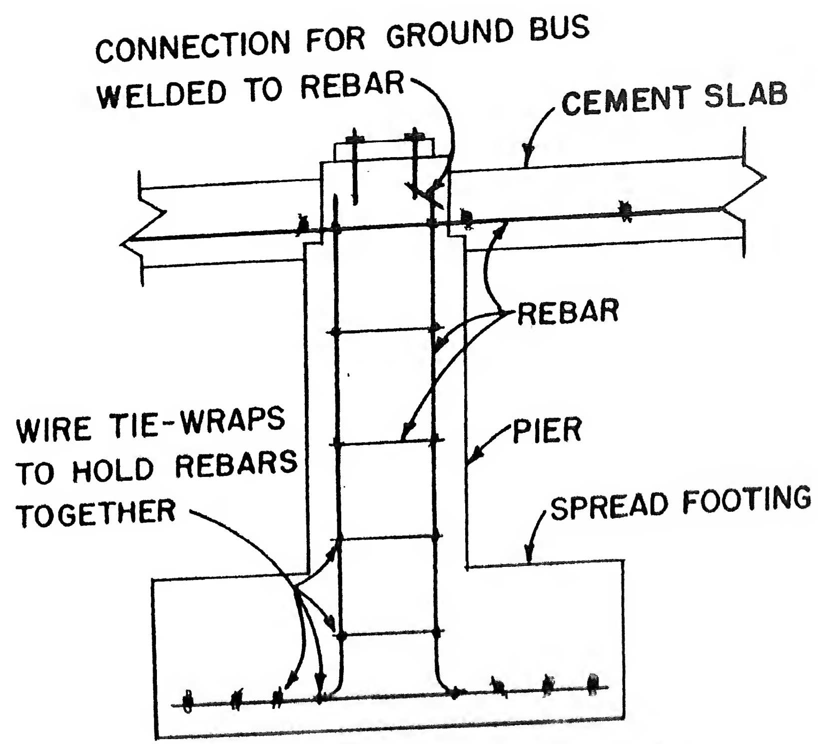


Fig. II–TYPICAL UFER GROUND INSTALLATION

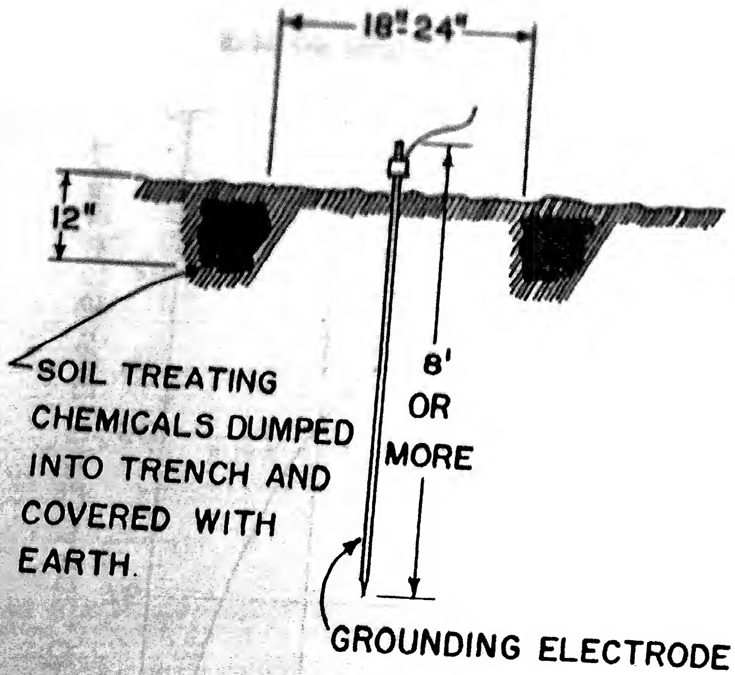


Fig.12-CHEMICAL TREATMENT OF SOIL TO IMPROVE GROUND CONNECTION

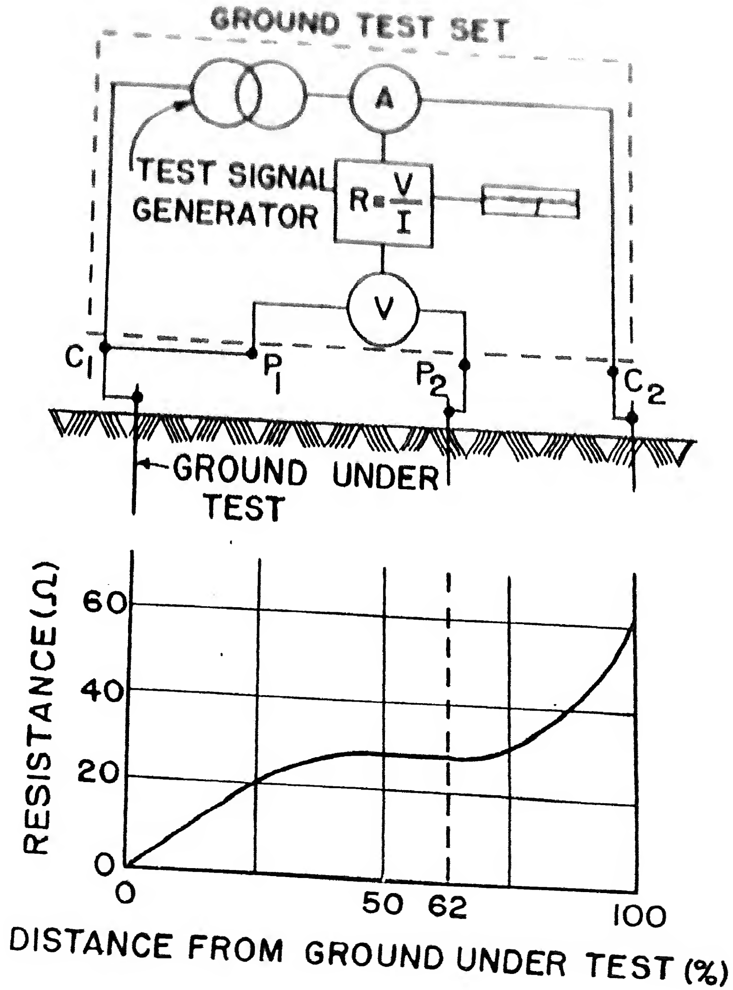
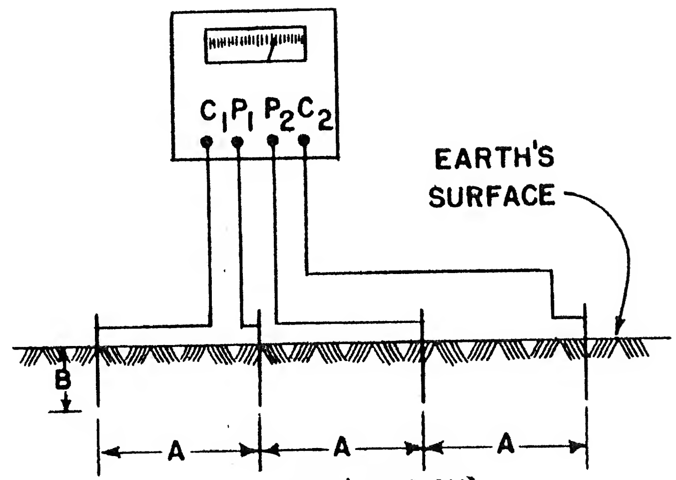


Fig.13-GROUND RESISTANCE TEST



A = 20B (APPROX)

$\rho = 2\pi AR$

Fig.15-PROBE PLACEMENT FOR 4 TERMINAL EARTH RESISTIVITY MEASUREMENT